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Bottom-up Monitoring of Municipal Energy and Climate Policy--More Than an Alternative to Top-Down Approaches?

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ABSTRACT

Policy evaluation is widely considered important for assessing policies for effectiveness and impact. Municipalities are among the political actors implementing energy and climate policy. Yet, few municipalities have introduced adequate instruments to monitor the effectiveness of their actions. Often, municipal actors consider local greenhouse gas inventories to be sufficient to monitor the impact of their actions. This paper points out why the expectations placed on local greenhouse gas inventories as a monitoring instrument can rarely be met in practice.

Based on German examples, it shall be shown that a thorough calculation of *actual* local energy and greenhouse gas reductions attributable to local efforts is often only partially possible, and is complicated by external factors.

A supplementary approach to the top-down method is to evaluate local programs from the bottom up. This paper discusses efforts to develop an instrument for a bottom up monitoring of the city of Hamburg's Climate Action Plan.

Keywords: municipal climate and energy policy; Climate Action Plan; greenhouse gas inventory; policy evaluation; top-down monitoring; bottom-up monitoring

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Introduction

The need to implement policies to reduce primary and final energy consumption by increasing energy efficiency is often justified with the necessity to mitigate climate change. Municipalities are widely seen and consider themselves an important actor for implementing policies to tackle global warming (Newman et al., 2009; OECD, 2010; United Nations Human Settlements Program, 2011). The majority of policies included in municipal climate action plans are aimed at avoiding emissions by reducing energy consumption (e.g. green retrofits or avoiding travel) or switching the primary energy source (e.g., use of renewable energies or changing the mode of transportation).

Currently, more than 6000 cities worldwide have committed to quantitative greenhouse gas (GHG) reduction targets, which are often more ambitious than the corresponding national targets (Hoornweg et al., 2011). The commitment to quantitative local GHG reduction targets implies the need for a local GHG inventory. Most GHG inventories are compiled by deriving local GHG emissions from data and estimations on local energy consumption via conversion factors.

But GHG inventories are not only used as an instrument to assess the total level of emissions. Many cities use local GHG inventories as a means to design and prioritize climate protection measures. Additionally, since a local GHG inventory will, or at least should, show the actual development of local GHG emission, many local policymakers consider GHG inventories to be an instrument to monitor the impacts of their local policies and legitimize their decisions (D' Avignon et al., 2010). The purpose of this paper is to critically discuss the expectations placed on local GHG inventories. Often these amount to:

- Analysis of the structure and patterns of local energy consumption and associated GHG emissions
- Monitoring of the effects of municipal climate policy
- Development or improvement of local climate or energy strategies
- Communication on the effects of local climate policy to citizens.

In this paper, we will concentrate on the question if local GHG inventories are an adequate tool to monitor the effects of municipal climate policy and whether a bottom-up approach may be better suited. In times where evidence-based policy making has become a maxim of increased importance, it seems relevant to study whether local GHG inventories can actually fulfill this expectation placed in them.

As a first step, we review literature on existing GHG protocols applicable for urban areas. Subsequently, we discuss the main pitfalls associated with using the existing GHG inventory approaches as an instrument to monitor the impact of energy and climate policies. Finally, we present an alternative approach for a bottom-up measurement as an additional and more accurate way of assessing the outcome of municipal actions. For the purpose of this paper, the use of energy balances and GHG inventories is referred to as a top-down approach because it utilizes aggregated data (mainly on energy consumption) to derive results. Bottom-up methods work by calculating or estimating energy savings and emission reductions for any individual case and measure and afterwards aggregating the results to infer the impact of all policies. The long-term monitoring of the local climate action plan of the city of Hamburg will be used as case study.

Top down measurements: GHG inventories and their strength and weaknesses

Review of existing methods for GHG inventories

As a response to the rising awareness of global warming as a pressing issue among the scientific, political and social landscape, several institutions have developed methodologies to measure urban GHG emissions. The International Council for Local Environmental Initiatives (ICLEI) was a forerunner in this field of activity by supporting the issue as part of the "Local Agenda 21" movement (Ibrahim et al., 2012). Nowadays, the following seven different methods for GHG inventories are those most applied to estimate GHG emissions of cities around the world:

- ICLEI
- Greenhouse Gas Regional Inventory Protocol (GRIP)
- European Commission´s Covenant of Mayors (EC-CoM)
- World Resources Institute (WRI)/ World Business Council for Sustainable Development (WBCSD) GHG Protocol
- International Organization for Standardization (ISO) 14064
- Bilan Carbone (ADEME)
- California Climate Action Registry Project Protocol

It is not the purpose of this paper to explain the aforementioned methods in detail. For more detailed information, we refer to Bertoldi et al. (2010), Ibrahim et al. (2012) and the respective manuals. At this point, the comparison made by Ibrahim et al. (2012) of ICLEI, EC-CoM, UN/WB and GRIP is sufficient to conclude that the existing GHG protocols are not fundamentally different. Their calculation methods or their concepts for dealing with insufficient data precision and missing data are quite similar. However, they differ with respect to assumed system boundaries and to the conventions for attributing emissions to the city. Here, urban GHG emissions inventories are distinct from methodologies developed for nation states, like the IPCC Guidelines for National Greenhouse Gas Inventories. While on the national level, all emissions originated from within the political borders are taken into account, urban emission profiles are more complex as cities have even more significant energy and trade flows to regions outside of their territory, and data on these flows are hardly ever collected. To solve this issue, the scope concept was developed to differentiate emissions associated to different system boundaries. Ibrahim et al. (2012) define these scopes in the following way:

- Scope 1: Direct emissions produced within the spatial boundary of the urban area.
- Scope 2: Indirect emissions produced outside the urban boundary, but as a direct result of activities within the boundary; limited to electricity and district heating/cooling.
- Scope 3: Further indirect or embodied emissions produced outside the urban boundary as a result of activities within the boundary.

While all protocols measure the emissions arising within the geopolitical boundary (Scope 1), upstream emissions from material and fuel consumption (Scope 2 and 3) are only accounted for in ICLEI and UN/WB. The differentiation of sub-sectors and if and how several sectors are reported differ as well. The latter is particularly crucial in regard to emissions from aviation. Though, it is evident that there is a need to harmonize the existing GHG protocols and to develop global standards for measuring urban GHG emissions as it is the case on the level of nation states. Currently, the World Resource Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) is partnering with ICLEI, C40, World Bank and UNEP and UN-Habitat to develop a Global Protocol for Community-Scale Greenhouse Gas Emissions (GPC) (Arikan et al., 2012). This common and worldwide applicable protocol focuses in particular on scope 3 emissions and will provide detailed guidance for measurement.

With the development of GPC, the scientific discussion about local GHG inventories and protocols is moving forward. So far, municipal inventories have mainly been conducted as production-based inventories neglecting the trade-flows and the shift of energy-intensive production from cities in developed countries to developing countries (carbon leakage) as it has occurred globally in the last decades. Kennedy et al. (2010) analyzed GHG emissions from ten global cities and concluded that upstream emissions from fuels would increase urban GHG emissions by up to 25 percent. This number shows that the current practice of allocating municipal GHG emissions may have unexpected and unintended effects, because it only partly reflects urban responsibility for GHG emissions, and thus may provide misleading incentives for municipal policy-makers (United Nations Human Settlements Program, 2011). In particular, for cities with a higher than average share of the tertiary sector the proportion of consumption-related emissions is significant, which reveals the necessity for a consumption-based inventory (scope 3). The consideration of trade flows and upstream emissions in local GHG inventories will have to be addressed, if cities further pursue low carbon targets. Furthermore, several GHG inventory tools have been developed additionally. For more detailed information about the strength and challenges associated with these tools, we refer to Bader and Bleischwitz (2009). Bader and Bleischwitz (2009) have examined six different GHG inventory tools.

Associated pitfalls of GHG inventories

There are a few different methods and tools for the compilation of local GHG inventories, which differ to certain degrees in how they address different methodological challenges. This paper aims to emphasize the interdependence between the way these methodological challenges are dealt with and the extent to which local GHG inventories are able to fulfill their perceived functions. In light of the important role of municipalities and municipal policies for climate change mitigation, GHG inventories are often understood as an instrument for prioritizing and selecting policy options (Kennedy et al., 2010). During the implementation of local action plans, a time series of local energy consumption and GHG inventories is seen as an instrument to monitor both the effectiveness of local policies and the degree to which a local mitigation target has been met. Yet, the extent to which local GHG inventories are able to meet these expectations is inextricably linked to the methodological challenges cities have to face during their compilation. This shall be exemplified for different challenges, as they have been summarized and explained by e.g. Bader and Bleischwitz (2009). Since the alternative approach to be presented aims at monitoring the effectiveness of local measures, the interdependence of the methodological challenges and the suitability of GHG inventories to support monitoring is particularly relevant. The named approach has been implemented in a German city and the following discussion is therefore mainly related to the German situation.

The following section presents in how far the variables identified by Bader and Bleischwitz (2009) are critical when it comes to using GHG inventories for selecting local policies and monitoring their effects.

Data availability: All methods and tools to compile local GHG inventories have to deal with problems of data availability. Ideally, primary data on the energy use of every possible energy source or carrier would be available and could even be differentiated with respect to the sector in which the energy is used. Data on the consumption of grid bound energy sources like electricity, natural gas and heat is often readily available in Germany and can even be differentiated according to end-use sectors. However, data on the consumption of other important energy sources like heating oil and coal is not regularly collected[1], and would therefore need to be calculated or estimated from secondary data. In the German case, this is often the number of heating systems, which are differentiated by fuel and nameplate capacity. Multiplied with an assumed or estimated value for full-load hours, one can calculate the consumption of heating oil, coal and other non-grid bound energy sources. But the need to resort to this method does compromise the usefulness of local GHG inventories for both selecting measures and policies and for evaluating the effectiveness of implemented action plans. A measure that aims to encourage green retrofit either by providing incentives, information or other forms of assistance, only results in a reduction of the consumption of non-grid-bound energy sources visible in the GHG inventory if it is accompanied by the installation of a new heating system that either has a lower nameplate capacity or burns a different fuel.

A similar uncertainty exists with respect to the fuel consumption for transportation. Since reliable data on the fuel consumption for purposes of transportation, either within the boundaries of the municipality (e.g. a city or county) or by the inhabitants of the municipality, is hardly available, these values also have to be estimated. Most often, even data on vehicle

[1] Industrial consumption of primary energy is an exception, since this type of data is regularly collected by a state government agency.

kilometres travelled on the municipality's territory or data on vehicle kilometres travelled by its citizens is not obtainable. In the German case, the only primary data that can be used concerns the local vehicle stocks differentiated by vehicle category. The fuel consumption has then to be derived by multiplying these figures with indicators derived from national statistics. Accordingly, the effects of a local policy, which aims to reduce vehicle use, will not be recorded in the local GHG inventory as long as it is not accompanied by a reduction of the number of registered vehicles. At the same time, policies implemented by a large number of other municipalities or by the federal government will affect the indicators used to calculate local fuel consumption. Limited data availability therefore results in a local GHG inventory that will not or very indirectly show the effects of local actions in an important field of municipal policy making.

Measurement boundaries and scopes: Before compiling a local GHG inventory, municipalities have to define the measurement boundaries and the scope of the inventory. The chosen scope affects the usefulness of a local GHG inventory for both setting up local action plans and monitoring its effects once implemented.

In the case of a local GHG inventory compiled according to scope 1, measures that aim to reduce the city's electricity consumption will not result in an emission reduction in the GHG inventory if it does not result in lower electricity production by local power plants[2]. This, of course, does not necessarily mean that no measures to reduce electricity consumption will be implemented, but nevertheless the importance of local GHG inventories for policy legitimation should not be underestimated. Most climate protection goals are formulated with respect to overall GHG emissions as they are measured by a local GHG inventories. A potentially expensive policy that reduces electricity consumption, but does not lead to lower emissions according to the local GHG inventory, therefore could seem politically unattractive.

Using scope 2 implies different consequences for the usability of local GHG inventories as a monitoring instrument. GHG emissions induced by electricity consumption are calculated by multiplying the electricity consumption with an emission factor. This emission factor is mostly computed based on the sources of electricity generation on the national level. Especially in Germany, national policies like the German Renewable Energy Act (Erneuerbare-Energien-Gesetz), which grants a feed-in-tariff for electricity generated with renewable energies, have led to an increasing share of renewable energy among the sources of electricity generation. Therefore, the emission factor of electricity has decreased in the past years and is expected to decrease further. Local GHG emissions as compiled in local GHG inventories thereby reduce quite automatically. Since local GHG inventories are based on local energy balances, one can still see the trend in electricity consumption. Yet, to what extent are municipalities willing to invest in policies furthering energy efficiency when electricity consumption becomes less costly in terms of the overarching goal of reducing GHG emissions?

External factors: The importance of external factors for local GHG inventories is not unique to inventories compiled according to scope 2 and not limited to the effects of national policies. Different external factors determine local energy consumption and GHG emissions to a greater extent than many municipal policies. Table 1 names some factors which influence local energy consumption, but can hardly be influenced by municipal policies.

Some of the external factors named in table 1 can be corrected for by using correction factors. For instance, the influence of weather patterns can be taken into account by using a cooling and heating degree days correction, respectively. The GHG emissions induced by electricity consumption can be made independent of the increasing share of renewable energies in electricity generation by using a constant emission factor, i.e. the one from the base year.

However, we are not aware of correction methods for every one of the named external factors. For the stated reasons, we deem energy balances and GHG inventories alone to be insufficient to monitor and evaluate the impact and efficacy of municipal energy and climate policy. In the subsequent section, we will present the bottom-up approach employed by the city of Hamburg to monitor the impact of their climate action plan. We consider this method to be complementary to GHG inventories in the task of monitoring local energy and climate policy.

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[2] Since the electricity production of power stations is mainly determined by wholesale electricity prices, which are dependent on (inter)national electricity demand and the marginal costs of available generation and interconnector capacity, drawing a causal connection between the electricity demand of the municipality the electricity generation plant is located in and the electricity output of this plant would seem far-fetched.

Table 1: Key external factors influencing local GHG emissions

Geophysical factors	
Weather patterns	e.g. winters that are colder than average tend to increase energy consumption; winters that are warmer to average tend to decrease energy consumption (Cao et al., 2004)
Economic factors	
Business cycle	Energy consumption of industrial enterprises is largely influenced by the business cycle; with higher energy consumption during expansions than during recessions (Thoma, 2004)
Income	Disposable income of private households is positively correlated with energy consumption (Druckman and Jackson, 2008)
energy prices	Primary energy prices are largely determined by world market prices and tax rates imposed by national and state governments. Energy consumption is not perfectly price inelastic (Kilian, 2008)
National and intergovernmental policies	
Building codes (e.g. German Energy Saving Ordinance)	Federal building codes set minimum standards for the energy efficiency of newly build and retrofitted buildings, which influences the overall energy consumption.
Renewable Energy Acts	Renewable Energy Acts aim at increasing the share of renewable energies among the sources of electricity generation and thereby decrease the emission factor of electricity and lower the overall emissions as compiled in local GHG inventories according to the activity principle
Technological factors	
Technological progress	Technological progress often leads to a decrease in energy intensity of the whole economy and an increase in energy efficiency of appliances. However, the question to what extent this technological change is policy-induced remains open (Popp, 2012)
Social factors	
Individual behavior	Studies show that energy conservation can be induced with interventions targeting individual behavior (Allcott, 2011) and that ideological perspectives are relevant for individual energy demand (Costa and Kahn, 2010).

Bottom-up monitoring – An introduction

The last section has shown that GHG inventories have grave limitations when it comes to using them as a tool for monitoring the effects of specific political measures and policies. But, in our view, the top-down method of compiling GHG inventories can be supplemented by a bottom-up monitoring scheme to improve the monitoring of local policies' effect.

Monitoring energy and climate policy from the bottom-up means to calculate the reduction in energy consumption and GHG emissions induced by a policy by calculating the reduction in energy consumption for every single specific measure (e.g. energy efficiency improvement, fuel switch) induced by this policy and deriving the total reduction by aggregating. The Directive 2006/32/EC of the European Parliament and of the Council defines a bottom-up calculation method in the following way:

> "A bottom-up calculation method means that energy savings obtained through the implementation of a specific energy efficiency improvement measure are measured in kilowatt-hours (kWh), in Joules (J) or in kilogram oil equivalent (kgoe) and added to energy savings results from other specific energy efficiency improvement measures." [*Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC*, p. 16]

Basically, bottom-up monitoring works by comparing two states: The energy consumption before the implementation of a specific measure or policy is compared to the energy consumption after the implementation of the respective measure or policy. Insofar, two questions have to be answered. What is the baseline, in this case the energy consumption or the GHG emission before the implementation of the measure or policy? And, which is often more complicated, which share of the observed change can be attributed to the measure or policy?

To do this, bottom-up monitoring can be based on various data. Vreuls et al. (2009) give an overview of the different types of data and methods, which can be utilized for bottom-up monitoring. Following, we will shortly recap the most important approaches. For a deeper discussion, we refer to Vreuls et al. (2009)

The two main paths to determine this change are:

- *Metering or billing data to identify the energy consumption before and after the implementation of a specific measure*

  This approach has the advantage that real data is used and that there is no need for estimating energy consumption. Yet, it also has two drawbacks. The data collection is very resource- and personnel-intensive and the metered individual energy consumption can often also be influenced by few external factors, most importantly weather patterns and a change in energy consumption behavior.

- *Estimations of the change in energy consumption based on engineering calculations*
  A change of energy demand is calculated by using standard engineering estimates, e.g. in the case of appliances or heating systems by multiplying nameplate power, load factor and annual duration of use before and after the implementation of a specific measure. The main advantages are that fewer and more easily available data can be used and that the result is not influenced by some external factors (e.g. weather patterns and changes in energy consumption behavior). The main disadvantage is that the resulting values are just estimates.

Certainly, bottom-up monitoring has its limitations as well. To name some major ones: Bottom-up monitoring is very resource- and personnel-intensive , i.e. costly. A lot of data has to be collected. At the same time, bottom-up monitoring is no catch-all approach to correct for all the external factors described in the last section. Many might in some cases as well affect the results in a bottom-up monitoring scheme and therefore have to be dealt with.

Nevertheless, we are convinced that bottom-up monitoring is a better approach to monitor the effects of municipal climate and energy policy than a GHG inventory alone. In the next section, we will explain the bottom-up-monitoring scheme, which has been developed to monitor the effects of the city of Hamburg's climate action plan.

The bottom-up monitoring of the climate action plan of Hamburg

The local government of the German city of Hamburg developed a local climate action plan in the year 2007, which has since been implemented. The action plan contains a number of measures in different sectors, with which the government wants to reduce carbon dioxide emissions by 2 million metric tonnes by 2012 compared to 2007 levels (Parliament of the Free and Hanseatic city of Hamburg, 2011). The different fields of activity of the Climate Action Plan are the energy sector, the building sector, the mobility sector, industry and plant technology, national and international cooperation, climate impact management and adaptation, research and evaluation and monitoring. Table 2 shows the number of measures in progress or preparation in 2011, completed or discontinued between December 2010 and December 2011 in each field of activity. The sum of allocated funds in the budgetary years 2011 and 2012 is also reported. The sum of available funds allocated to measures of the Climate Action Plan amounted to 34 million EUR in the year 2011 and 20 million EUR in the year 2012.

Table 2: Measures and funds of the climate action plan of Hamburg

Sector	number of measures	funds allocated 2011 [€]	funds allocated 2012 [€]
Energy	49	3,239,180.00	2,590,000.00
building	79	16,485,282.00	5,434,000.00
mobility	46	2,696,973.00	3,386,598.00
industry and plant	36	3,472,365.00	4,502,365.00
national and international coordination	17	65,000.00	176,703.00
climate impact management	21	2,495,000.00	235,000.00
awareness raising	65	1,921,950.00	1,104,948.00
research	28	650,000.00	127,000.00
evaluation and monitoring	9	1,385,000.00	1,235,000.00
∑	350	32,410,750.00	18,791,614.00

source: Parliament of the Free and Hanseatic city of Hamburg (2011)

Hamburg's mitigation goal is also stated with respect to the city's overall emissions, as they are compiled in a local GHG inventory. At the same time, the local government recognizes that the degree of achievement of the objectives will be dependent on a number of factors. National and intergovernmental policies, technological change and the business cycle are among these factors, but not the only ones (see table 1). Therefore the city of Hamburg decided to estimate the effects of the individual measures bottom-up, complementary to the compilation of a top down inventory to which the city (and Germany) is committed. However, there has not yet been developed an adequate and comprehensive methodology for calculating the additional effects of climate action at the local level. .Following, the general approach, which subsequently has been applied to the measures within the climate action plan of Hamburg is presented and explained. .

The unknown variable is the difference in the carbon dioxide emissions of the addressed object before and after the implementation of an individual measure (For a list of abbreviations, see Table 3). These are dependent on the object's energy consumption and the carbon content of the energy source. Therefore the following equation can be set up straightforwardly:

(I) $\Delta EM_{CO_2} = (n \times EC_{t+1} \times EF_{t+1}) - (n \times EC_t \times EF_t),$

where EC denotes the energy consumption, EF denotes the emission factor of the particular energy source, EMCO2 denotes the carbon dioxide emissions and t refers to a point in time before the implementation of the individual measure (usually 2007), while t+1 refers to a point in time after the implementation of the individual measure (usually one of the years between 2008 and 2012).

Table 3: Table of Abbreviations

Abbreviation	Definition
EC	Energy Consumption
EF	Emission Factor
EM	Emissions
EX	Influence of external factors
M	Multiplier Effect
n	Number of cases
NP	Influence of national policies
R	Rebound Effect

At the same time, multiplier and rebound effects have to be considered. A multiplier effect occurs whenever an individual measure leads to further emission reductions by actors, who were not directly addressed, e.g. due to information dissemination. A rebound effect occurs when increased energy efficiency leads to a more frequent use of certain appliances or the monetary savings due to lower energy consumption are spent for other energy consuming activities. Principally, these effects have to be considered as well and are introduced into the equation in the following way:

(II) $\Delta EM_{CO_2} = [(n \times EC_{t+1} \times EF_{t+1}) - (n \times EC_t \times EF_t)] \times (1 + M - R),$

where M denotes the multiplier effect and R denotes the rebound effect. M and R can take values between 0 and 1. Yet, even carbon dioxide emissions and energy consumption directly addressed by local measures are influenced by national policies and technological change. For instance, the reduction in energy consumption and carbon dioxide emission due to the green retrofit of a building, which has been publicly sponsored by the municipality, may be partly also due to stricter building codes on the national level (i.e. national policy) and is dependent on the availability of insulation materials (i.e. technological change). These factors are integrated into the equation as follows:

(III) $\Delta EM_{CO_2} = [(n \times EC_{t+1} \times EF_{t+1}) - (n \times EC_t \times EF_t)] \times (1 + M - R) \times (1 - NP - EX),$

where NP denotes an estimator for the share of emission reduction induced by national policy and EX denotes an estimator for the share of emission reduction due to external factors like energy price increase and technological change. EX and NP can as well take values between 0 and 1. While the equation itself is quite straightforward, the estimation of M, R, NP and EX is not. In case of the city of Hamburg, the estimation of these coefficients had often to be based on theoretical considerations and ad-hoc assumptions.

In the following, the application of the described methodology is presented for the thermal retrofit program "Wärmeschutz im Gebäudebestand", which is a green retrofit supporting program by the city of Hamburg. Under predefined conditions, homeowners are eligible for financial support for a planned green retrofit. These conditions refer to minimum requirements for insulation materials to be installed. The city administration collects the following data:

- number of applications
- number of beneficiaries and allocated funds

for individual cases:

- floor area [in square meters]
- installed insulation [in square meters]
- investment costs
- resulting reduction of energy consumption [possibly estimated]
- resulting reduction of carbon dioxide emissions [as calculated]

The collected data and additional assumptions have to be plugged into equation (III) to monitor the effectiveness of the measure in question. The values for energy consumption EC at t and t+1 can either be based on actual energy consumption data before and after the green retrofit or on an estimation of the energy demand after green retrofit, as calculated by a civil engineer. The value chosen for the emission factor EF is dependent on the energy source for heating the building. These emission factors have been standardized with respect to each individual energy source.

The coefficients M, R, NP and EX are more challenging. In the present case, both the multiplier effect and the rebound effect are assumed to be zero. Statistical data on the total number of green retrofits in Hamburg is not available, but it is assumed that every homeowner planning a green retrofitting eligible for financial support will make use of this opportunity. Searching for studies on the rebound effect associated with green retrofitting reveals the lack of a definite distinction of "actual" rebound effects and significantly varying results. Chitnis et al. (2013) distinguish direct and indirect rebound effects. Direct rebounds result from a more extensive use of energy efficient appliances because the use of this appliance has become relatively cheaper. Since the reduced energy consumption also implies lower expenditures for energy, the money saved can be used to consume other goods and services, which may possibly be more energy- and/or carbon-intensive. These effects are called indirect rebound. We will only consider direct rebound effects here. While one study calculates the direct rebound effect in cases of improving the heating system to be about 12% (Chitnis et al., 2013), other authors estimate higher values (Sorrell et al., 2009). In the monitoring scheme implemented by the city administration of Hamburg, the value of R is implicitly assumed to be zero. The city administration mainly collects data on the expected reduction in energy demand for each individual retrofitting as estimated by a civil engineer. Because these values are ex-ante estimations of the reduction in energy demand, they are not based on observed changes in energy consumption after the retrofitting took place. Within the monitoring scheme data on energy consumption, which could show rebound effects, is not collected. Such a data collection would be both very resource- and personnel-intensive and therefore is not part of the monitoring scheme. Unfortunately this likely leads to an overestimation of attained reductions in energy consumption and carbon dioxide emissions that has to be kept in mind when interpreting the results.

Selecting values for NP and EX is more difficult and requires a differentiated approach. The federal government has instituted several policies to support the green retrofit of existing building. Among these is a regular amendment to the national building codes, the so called "Energieeinsparverordnung (EnEV, Energy Saving Ordinance)", which subsequently imposes stricter standards. At the same time, green retrofits are assisted with public subsidies and low-interest loans by the state-owned bank KfW. Homeowners getting funds out of "Wärmeschutz im Gebäudebe-stand", are still eligible for financial support by the federal government. Technological change constitutes a prerequisite for the reductions of energy consumption achieved, since the attainment of those is dependent on the availability of insulation materials. Concurrently, a green retrofit itself can be economical depending on expected energy price rise, individual discount rates, and investment costs, among other things. In this case, a specific green retrofit would not be dependent on the municipal support and the funds would only be used to maximize individual revenue.

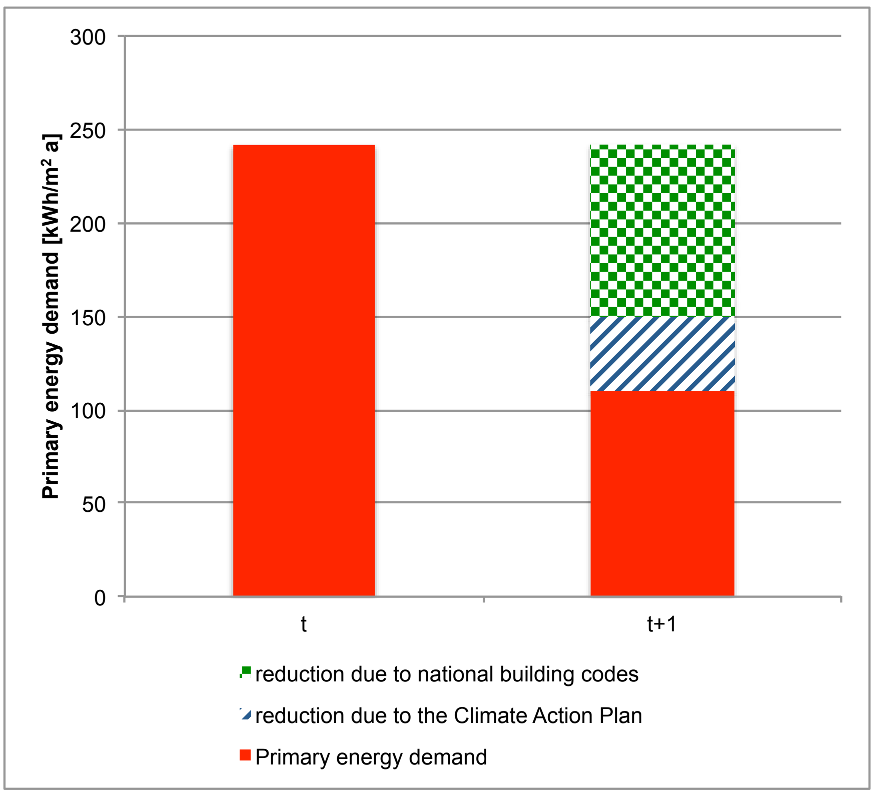

Figure 1: A hypothetical green retrofit

The influence of external factors refers to the broader question for the existence of an energy-efficiency gap, which can hardly be answered by a city administration that wants to monitor the effectiveness of implemented policies. Nevertheless, experience shows that even when economic calculations yield that green retrofits are in many cases economical under usual assumptions, they are not implemented in the high numbers one would expect. Hence, setting EX to zero appears to be justifiable as a simplifying assumption.

Given the aforementioned assumptions and considerations, the reduction of carbon dioxide emissions due to this policy can be calculated with the following formula:

(IV) $\Delta EM_{CO_2} = \sum_{i=1}^{n}\{[(EC_{i,t+1} \times EF_{i,t+1}) - (EC_{i,t} \times EF_{i,t})] \times (1 - NP_i)\}$

where i denotes any individual case out of the population or the sample (For a graphical representation, see Figure 1).

Conclusions

An increasing number of cities worldwide are setting mitigation targets for themselves and are developing climate action plans. The compilation of a local energy balance and GHG inventory is often part of the process. These shall help both selecting policy options and measures and monitoring the progress with respect to attaining the set mitigation targets. The first part of this paper dealt with the question, to what extent GHG inventories may also be used as a tool for monitoring the impacts of local climate protection measures. The implementation of municipal energy and climate policy requires, sometimes substantial, (financial) resources. This sets a strong incentive for the implementation of instruments which allow for an evidence-based policy making. Policymakers have to know the effects and impacts of their policies. The first main thesis discussed in our paper is that local GHG inventories are an instrument of limited usability for monitoring the effectiveness of local policies. The section of this paper dealing with GHG inventory pitfalls has shown how missing data, the deliberate selection of measurement boundaries and external factors affect the outcome of a local GHG inventory and hinder its usability for the aforementioned purposes. At the same time, we still deem local energy balances and GHG inventories to be an adequate instrument – when compiled according to a sound protocol – to answer a different but very important question: What is the total energy consumption by the city's population and economy and what GHG emissions does this energy consumption cause?

Our second main thesis is, that a bottom-up approach is better suited to address the need for a monitoring of the effectiveness of local energy and climate policies. The city administration of Hamburg has implemented such an approach for the measures in their climate action plan.. The general methodological outline of bottom-up monitoring has been explained, before it was exemplified for a specific policy.

The method has been implemented by the city administration of Hamburg for every measure in its climate action plan for which it was considered applicable. A report on the results was published in 2013 (Bürgerschaft der Freien und Hansestadt Hamburg, 2013). This report also considers the results of a bottom-up monitoring of the effects of national energy and climate policy in Hamburg (Kaselofsky et al., 2013). Yet, some limitations and uncertainties remain with regards to bottom-up monitoring. Especially the estimation of M, R, NP and EX stays difficult, and the results also partly suffer from limited data availability and precision. Bottom-up monitoring should supplement, rather than replace, local energy balances and GHG inventories, since the methodologies used are completely different. Energy balances and GHG inventories track the total energy consumption and GHG emissions. Changes in energy consumption and associated GHG emissions can result from a variety of external factors unrelated to local policy. The bottom-up methodology calculates energy conservation and associated emission reductions compared to a base case (e.g. a non-retrofitted building). Therefore the sum of energy conserved and emissions mitigated will never equal the trend observed in the top-down approach. In contrast, while the energy balance can show that the city's total energy consumption has increased, one can still conclude based on the bottom-up monitoring that the energy and climate policy led to an emission reduction compared to a (counterfactual) base case. Anyhow, the compilation of a local GHG inventory remains a necessary task if one wants to assess the total energy consumption and GHG emissions on the city's territory or induced by the city's population, respectively.

A bottom-up approach can be considered a worthwhile attempt at bettering the evaluation and monitoring of municipal climate policy. The reason for this is that it aims to evaluate the effectiveness of municipal climate policy by quantifying the emission reduction achieved by every individual measure and not only by asking whether set overall emission reduction targets have been attained or not. However, bottom-up approaches have their own limitations and shortcomings. Among the most important ones surely is that bottom-up methods imply the need for an extensive data collection and therefore take up a lot of resources. A trade-off exists between the importance of evidence-based policy making and the investment of considerable financial resources to provide this evidence. This warrants further research on better and more easily implementable methods for an impact assessment of municipal energy and climate policy.

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